UNBOUNDED IRRATIONALITY: MEMORY, INDIVIDUAL DIFFERENCES, FRAMING EFFECTS, AND FUZZY-TRACE THEORY

A Thesis

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by

Jonathan Corbin

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ABSTRACT

This study tests the assumption that processing limitations (in working memory capacity and numeracy) underlie biased decision-making. In these experiments, access to framing information during decision-making was manipulated. Having access to the information led to larger framing biases. Counterintuitively, higher working memory predicted more framing bias, except for in those with high numeracy, suggesting spontaneous conversion between frames for high numerates.

In a second experiment, relationships between memory for the problem information and decision-making were analyzed. Crucial for the some-none comparison underlying framing effects, memory for the zero-complement was related to more framing. Memory for the endowment (total lives at risk), which is crucial for spontaneous conversion between frames, led to less bias. Results support fuzzy-trace theory's conception of framing effects, specifically that bias is linked to gist (i.e., meaningful representations of the problem), whereas reduced framing is linked to rote calculation (i.e., verbatim processing).

BIOGRAPHICAL SKETCH

Jonathan Corbin is currently a third year PhD student in Cornell University's Department of Human Development. He earned his B.S. in Psychology in 2008 from the University of North Carolina at Asheville and a M.A. in Experimental Psychology from Appalachian State University. He grew up in Jacksonville, NC and now resides in Ithaca, NY. His current research explores the relationship between memory and decision making.

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Unbounded Irrationality: Memory, Individual Differences, Framing Effects, and Fuzzy-Trace Theory

George Miller's discovery of "the magical number 7" (Miller, 1956) had a large effect on the field of decision making, providing a clue to why individual's demonstrate systematic violations of basic tenets of rationality theory. In essence our ability to make rational decisions was bounded by our cognitive resources. Therefore, humans must rely on mental shortcuts, or heuristics, which lead to systematic biases in decision-making. This information-processing approach to decision-making has dominated the field, leading to several theories that incorporate memory limitations as a foundational reason for biased decision-making (Evans, 2008; Kahneman & Frederick, 2002).

One such bias is the risky-choice framing effect, whereby individuals demonstrate opposing preferences when a decision is framed in terms of gains opposed to losses. The classic example of this effect was demonstrated by Tversky and Kahneman's (1981) classic Asian Disease problem, in which participants were told that 600 lives were at risk of dying from a disease. They were given two options to combat this disease, which were framed either in terms of people being saved (gains) or people dying (losses):

A: 200 people saved for sure.

B: 1/3 chance 600 people saved, 2/3 chance 0 people saved.

C: 400 people die for sure.

D: 1/3 chance 0 people die, 2/3 chance 600 people die.

Although the outcomes remain the same, framing the problem in terms of gains led people to choose the sure option (option A), whereas framing the problem in terms of losses led people to choose the risky option (option D), thus violating descriptive invariance (i.e., preferences should remain stable regardless of how a decision is described provided the outcomes are identical). According to prospect theory (Kahneman & Tversky, 1979), decision-makers adopt whichever frame is presented (gain, or loss), and transform objective values and probabilities (which maintain a linear relationship) into subjective values, which maintain a curvilinear relationship dependent on frame. The value described by prospect theory is S-shaped, and as compared to a neutral reference point, the curve is concave in the domain of gains (yielding risk-averse preferences), and convex in terms of losses (yielding risk-seeking preferences).

The research on the relationship between the framing effect and individual differences has largely been aimed at testing whether individual differences may moderate the shape of the value function described by prospect theory. Specifically, the general hypothesis has been that if limitations in cognitive ability or capacity underlie biases in decision-making, we should see less bias in those with higher ability. Most theoretical accounts of framing assume that individual's must rely on executive functions to resist giving into the framing bias, which is assumed to result from fast, intuitive processing of the information in the framing problem (De Martino, Kumaran, Symour, & Dolan, 2006; Evans, 2008; Kahneman & Frederick, 2007; Levin & Gaeth, 1988; Levin, Schneider, & Gaeth, 1998; Stanovich, 2008). In other words, for individuals with more cognitive ability (and/or capacity), the S-shaped value function of prospect theory should be more linear compared to those with lower ability (Peters & Levin, 2008).

A number of studies have demonstrated relationships between cognitive ability and decreased framing effects with respect to within-subject framing (i.e., participants receive both gain and loss frames; Bruine de Bruin, Parker, & Fischhoff, 2012; Del

Missier, Mäntylä, & Bruine de Bruin, 2012; Del Missier, Mäntylä, Hansson & Bruine de Bruin, 2013; Parker & Fischhoff, 2005; Stanovich & West, 1998). The issue with these studies is that they measure more than just the impact of frame on decisions; they also measure a participant's ability to recognize equivalent frames once they both have been presented (Kahneman, 2000). Differences between within and between subjects designs were highlighted by LeBoeuf and Shafir (2003), who found that a need for cognition thinking disposition was associated with a decrease in framing in a within-subject design, but showed no relationship in a between-subject design. Whereas, within-subjects designs may allow a greater understanding of how individual differences may relate to one's ability to recognize equivalent frames, they do not shed light on how individual differences relate to the framing effect when participants are only given one version of the problem.

As for between-subjects designs, Simon, Fagley, and Hallerin (2004) demonstrated that individuals high in need for cognition (Cacioppo & Petty, 1982) and high in self-rated math ability showed smaller framing effects, individual's with a more analytical style of thinking have shown smaller framing effects compared to those with a holistic style of thinking (McElroy & Seta, 2003). Furthermore, higher numeracy has been related to less susceptibility to attribute framing (rating an item as more favorable when described by a positive attribute (80% fat free) as compared to an equivalent negative attribute (20% fat); Peters, Västfjäll, Slovic, Mertz, Mazzocco, & Dickert, 2006). Stanovich and West (2008) did not find a relationship between cognitive ability (as measured by SAT scores) and framing. On the other hand, Corbin, McElroy, and Black (2010) showed that *higher* working memory capacity (as measured by the

Operation Span; Unsworth, Heitz, Schrock, & Engle, 2005) was related to larger framing effects.

The results from these studies suggest two types of processing that lead to opposing outcomes. Individual's with a propensity toward seeing the framing problem as a math problem tend to be less affected by the frame, whereas when it is seen as a meaningful narrative, framing effects appear (Reyna, 2008). This dichotomy has been experimentally tested by either cuing participants to think of the framing problem as a statistical problem, or by cuing them to think of it as a medical decision-making problem (Bless, Betsch, & Franzen, 1998; Igou & Bless, 2007). Participants in the statistical cuing condition were generally unaffected by the framing manipulation, whereas framing effects were found in the medical cuing condition. Also, manipulations that increased motivation to think about the problem, or increase time available to make one's decision have been found to elicit larger framing effects than manipulations that decrease motivation and processing time (Igou & Bless, 2007). The conflicting findings of smaller framing effects relating to higher numeracy and larger framing effects relating to higher working memory capacity are not easily explained by the theoretical viewpoints previously mentioned. That is, dual-process theories have suggested that numeracy is a marker of advanced executive processes (e.g., Peters et al., 2006). Previous theoretical approaches to framing would also assume that the same relationship would exist for working memory and framing. Given that the driving assumptions behind irrational choice involved limited memory capacity forcing individual's to rely on mental shortcuts, demonstrating that bias actually can increase with higher memory capacity (as well as increased motivation to thoroughly process the information) requires a critical look at the traditional viewpoint. Whereas traditional theories struggle with the apparent duality between numeracy and WMC, these affects can, however, be accounted for by fuzzy-trace theory.

Fuzzy-Trace Theory and Framing Effects

Fuzzy-trace theory (FTT) points to similar dual processes that underlie false memory effects as the basis for framing effects. Memory research has shown that rates of false memory can be decreased by focusing people on the surface features of words, and false memory can be increased by focusing participants on the meaningful connections between the words in the task (Holliday, Brainerd, & Reyna, 2011). Similarly, participants taking a quantitative (verbatim) approach to framing problems should show less framing whereas participants who focus on the underlying meaning (i.e., gist) of the problem should show larger framing effects. For FTT, framing effects do not arise due to processing limitations, but rather occur because of a reliance on meaningful gist representations of the problem. In traditional risky-choice framing problems, expected values are equal between the options (e.g, given $600, a sure possibility of keeping $200 and 1/3 chance of keeping $600 are mathematically equivalent outcomes), meaning that a verbatim approach leads to indifference between the options. Conversely, FTT predicts that the gist of the problem is the categorical distinction between saving some and saving none, or losing some and losing none, which lends itself to preference reversals dependent on the frame. Previous work has supported this view, demonstrating that by emphasizing or de-emphasizing the some/none distinction in framing problems (Kuhberger & Tanner, 2010, Reyna & Brainerd, 1991; 2011). This was specifically done by only presenting participants with the zero-complement of the risky option in the framing problem (e.g., 1/3 chance 0 people saved), which created larger framing effects compared to the traditional version, or by only presenting participants with the non-zero complement of the risky option (e.g., 2/3 chance 600 people saved), which eliminated framing effects. Also in line with developmental reversals in false memory (increases in false memory with age; Brainerd, Reyna, & Zember, 2011), previous work has demonstrated developmental reversals in framing effects (Reyna & Ellis, 1994). It is important to note that FTT does not consider gist to be akin to rote associative intuition, but rather it lies at the intersection of meaningful comprehension and intuition (Reyna, 2012).

Fuzzy-trace theory can nicely account for the negative relationship between numeracy and framing due to the fact that rote calculation would be considered verbatim processing (Liberali, Reyna, Furlan, Stein, & Pardo, 2012). Participants who focus more on the magnitudes in the framing problem are less likely to substantively process the meaningful information conveyed by the frame, and are therefore less likely to show biased decision-making. FTT can also account for the positive relationship between working memory capacity and framing given that higher working memory capacity is related to more elaborative encoding of stimuli (i.e., processing gist rather than just rote rehearsal or reliance on surface information (Cokely & Kelley, 2009; Cokely, Kelley, & Gilchrist, 2006).

Experiment 1

One goal of experiment one was to test theoretical assumptions about the role of memory capacity limitations in biased decision-making. To achieve this, Hastie and Park's (1986) online versus memory-based manipulation was adapted for the framing problem. Participants were either required to make their decision online (i.e., with all relevant problem information available during decision making), or to rely on their memory for the problem to make their decision (i.e., memory-based). If memory capacity limitations underlie framing effects, then participants in the memory-based condition should show larger framing effects as compared to those making their decision online. Furthermore, one would expect to see a negative relationship between actual memory for the framing problem and biased decisions. Alternatively, if framing effects are a result of substantive processing of the meaningful content in the problem, larger framing effects should be found in the online condition.

The second purpose of experiment 1 is to assess the relationship between working memory capacity, numeracy, and choice on the framing task. Previous research suggests that numeracy is related to smaller framing effects whereas higher WMC is related to larger framing effects. No previous study has measured both numeracy and WMC in the context of a between-subjects framing task. Therefore the current study seeks to determine how these individual differences relate to biased decision making.

Method

Participants. A total of 256 participants (63.2% female; M_{Age} = 20.85, SD = 6.3) completed the experiment online using Cornell's participant pool and were offered course credit, or were recruited on online social networking sites. Participants were 58.2% White; 4.3% Black, 11.3% Asian, 2.3% Indian, 3.5% other and 9.8% did not answer. The sample was 6.8% Hispanic.

Materials. Participants were given the classic dread disease framing problem (Tversky & Kahneman, 1981) as well as a cued recall test in which participants were given the disease scenario and options, with blanks in place of the numerical information, for a total of 6 memory items. Finally, participants received a number of individual difference scales. Participants received an online version of the Operation Span Task which measures working memory capacity (Lin, 2007). During this task participants are presented with words to recall later (in order of presentation) while also verifying simple math problems (e.g., (1 X 3) – 3 = 0) between presentation of words. Participants also received the 11-item Lipkus-Schwartz numeracy scale (Lipkus, Samsa, & Rimer, 2001; Schwartz, Woloshin, Black, & Welch, 1997), the 12-item short form of Raven's Avanced Progressive Matrices (APM) (Arthur & Day, 1994; Raven, Raven, & Court, 1998).

Procedure. The experiment took place online using Qualtrics (Qualtrics Labs Inc., Provo, UT). At the beginning of the experiment, participants read instructions that stated that they would be asked to make some decisions and would be subject to memory testing. They were prompted to focus on their decisions. Participants were then given the framing problem, but were not prompted to make a decision between Program A (save 200 lives for sure) and Program B (1/3 chance to save 600 lives, 2/3 chance to save 0 lives). When prompted to make a decision, participants were either given access to the problem information (online task) or participants were asked to decide between program A or B without access to the problem information (memory-based). Order of presentation of the decision and memory task was counterbalanced such that participants either received the decision prompt prior to memory testing (decision first) or they received the decision prompt after memory testing (decision second). Then participants were prompted to rate their confidence in their decision on a 7-point Likert scale ranging from 1 – Not at All Confident to 7 – Completely Confident. The complete design was a 2

Frame (Gain, Loss) X 2 (Task Type; Online, Memory-Based) X 2 (Presentation order; Decision First, Decision Second) between subjects factorial. After participants completed their decision and memory test, they were given the individual difference scales.

Results

All analyses involving framing choice were measured using two dependent variables, the first being binary choice (e.g., 0 = Program A (sure option); 1= Program B (risky option). The second dependent variable takes advantage of participants' confidence ratings by multiplying confidence ratings by -1 if participants chose Program A to end up with a framing signed confidence scale ranging from -7 (highly confident risk aversion) to 7 (highly confident risk seeking).

We performed two 2 (Frame: Gain, Loss) x 2 (Task type: Online, Memory-Based) x 2 (Presentation Order: Decision First, Decision Second) between-subjects ANOVAs with choice and signed confidence as the dependent variables to determine the effect of an online versus memory-based task on framing. There was an overall significant effect of frame (M_{Gain} = 0.28, M_{Loss} = 0.60), as well as a significant frame X task type interaction whereby framing effects were larger in the online condition (M_{Gain} = .2, *SD* = .41, M_{Loss} = .67, *SD* = .47) than the memory-based condition (M_{Gain} = .32, *SD* = .47, M_{Loss} = .58, *SD* = .5). Furthermore, there was a significant frame X task type X scenario order interaction in which the previous interaction only held when the decision prompt came before the memory test (see Figure 1). The above results were unchanged when memory score was added as a covariate to the analysis, suggesting that any differences due to the presence or absence of problem information were not due to participants' ability to actively recall problem information.

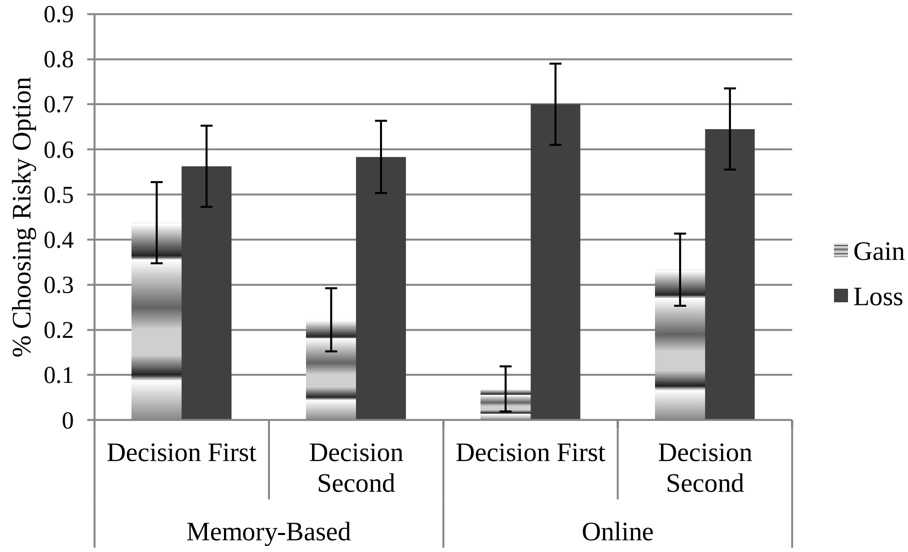

Figure 1. Experiment 1 Results for Task Manipulations Between Frames
Note: Error bars are Standard Errors based on 1,000 bootstrap samples.

Framing, working memory, and numeracy. For the individual differences analyses, we are relying on a reduced sample of 161 participants due to software errors that prevented some participants from completing the working memory span task. Descriptive statistics for individual difference measures can be found in Table 2 and correlations in Table 3.

First we looked at bivariate correlations between the measure of working memory capacity (WMC) and choice for each frame separately (correlations were based on 1,000 bootstrapped samples). Analyses revealed that WMC is significantly correlated with choice in the gain frame such that higher WMC is related to more risk-aversion (i.e., choosing in the direction of normal framing) r(80) = -.36, p = .001, 95% CI [-.54, -.14].

However, there is no significant relationship between WMC and choice in the loss frame r(81) = .06, *p* = n.s., 95% CI [-.15, .28].

In order to look at the relationships among working memory capacity (WMC), numeracy, and framing, a factorial logistic regression was performed with framing choice as the dependent measure (see Table 4; see also Table 5 for signed confidence analyses). The interaction of frame and WMC indicates that those with higher WMC show larger framing effects. This interaction is qualified by a 3-way interaction of frame, WMC, and numeracy. Simple slopes analysis reveal that for those with lower numeracy (set at 1 *SD* below the mean) higher WMC results in larger framing effects B = -.612, *SE* = .235, *z* = -2.61, *p* = .009, 95% CI [-1.072, -0.153] but for those with higher numeracy (set at 1 SD above the mean), WMC does not significantly interact with frame B = -.009, *SE* = .19, *z* = -.047, n.s., 95% CI [-0.381, 0.363]. Furthermore, results show that with high WMC (set at 1 SD above the mean), framing decreases as numeracy scores increase B = 1.129, *SE* = .506, *z* = 2.229, *p* = .026, 95% CI [0.136, 2.121]. In sum, framing effects are larger for low numeracy/high WMC participants but smaller for high numeracy/high WMC participants. This pattern persists even when controlling for intelligence (as measured by Raven's APM), as well as controlling for the type of task (online vs. memory-based) and presentation order (decision first, decision second).

Discussion

Results from study 1 suggest that requiring participants to rely on memory can actually diminish the effect of the frame on one's decision. Interestingly, this effect is unrelated to participants' ability to actively recall the problem information. These findings do not support memory capacity limitation explanations for framing effects.

Whereas capacity-limitation accounts would expect to see more framing when participants are required to rely on memory for their decision, participants show larger effects when the problem information is easily accessible. Therefore, framing effects may not necessarily be due to a fast, automatic heuristic, but rather that framing effects may be a result of more cognitive effort (or more advanced processing) as opposed to less.

The individual-difference analyses also support the conclusion that framing effects are not the result of fast, automatic processes. The finding that individuals with higher working memory capacity (WMC) show larger framing effects supports the hypothesis that frame-consistent decisions are the product of effortful processing that taps working memory resources. Interestingly, this effect is moderated by numeracy, whereby the combination of high WMC and high numeracy leads to reduced framing. It appears that individuals high in WMC and numeracy may be more likely to treat the decision as a math problem (i.e., rely on verbatim calculation) whereas individual's high in WMC but low in numeracy may prefer to rely on contextual features (i.e., the gist) of the problem to make their decision.

Experiment 2

Experiment 1 showed support for the hypothesis that framing effects are due to substantive processing of the contextual information in the decision problem. As can be seen by participants' memory performance in Experiment 1, the memory task provided little challenge (especially given that a decision prompt almost immediately followed presentation of the problem information). The next experiment seeks to increase the memory demands during the task by requiring participants to keep information from a number of unrelated tasks active in memory during decision making as well as an additional delay between presentation of the problem and prompting a decision. This will allow for a further test of whether actual memory for the framing problem information affects decision making in an online task versus a memory-based task. Furthermore, the following experiment examines the relationship between memory for different aspects of the problem and framing. Specifically, this experiment focuses on the relationship between framing and participants' memory for the zero complement (e.g., a chance that 0 die/0 are saved) and the endowment (e.g., 600 lives total at risk) in the problem. Given that fuzzy-trace theory predicts that focusing on the zero complement is crucial for the framing effect (focusing on saving none encourages risk-aversion and focusing on losing none encourages risk-seeking), the straightforward prediction arises that participants who correctly recall the zero complement will show larger framing effects. On the other hand, the endowment is what ensures that the gain and loss versions of the problem are equivalent (i.e., with 600 lives at risk saving 200 is equivalent to losing 400). Therefore, focusing on the endowment should lead to reduced framing as compared to those who do not recall the endowment (for which the gain and loss frames are no longer equivalent).

Finally, this manipulation serves to determine the relationship between high working memory capacity and framing when the demands on memory for the problem are increased. In contrast to Experiment 1, in which there was little demand, in Experiment 2 we expect to see a relationship between memory for the problem, working memory capacity, and decision-making.

Method

Participants. A total of 306 participants (64.7% female, 22.4% male, 12.8% did not answer; M_{Age} = 20.05, *SD* = 1.56) completed the experiment and were recruited online using Cornell's participant pool and were offered course credit, or were recruited on online social networking sites. Participants were 54.5% White; 6.4% Black, 18.8% Asian, and 4.5% mixed ethnicity, 1.3% other, and 12.8% did not answer. The sample was 7.7% Hispanic.

Procedure. The experiment took place online using Qualtrics (Qualtrics Labs Inc., Provo, UT). The design was the same as the first experiment with a few exceptions. First, the level of difficulty for the memory test was increased, by adding a brief delay (during which participants were given 5 unrelated decision and memory tasks in the same format as the framing task; see Appendix D) between presentation of the scenario and memory test. Second, in the online condition, the memory order condition was collapsed so that participants were given the scenario and decision simultaneously, which was then followed by a memory test. In the memory-based condition, we still counterbalanced the order of the memory test to see if this interacted with the added delay. The same individual-difference measures were given as in Experiment 1.

Results

First, we performed a 2 (frame; gain, loss) X 2 (presentation order; decision first, decision second) ANOVA with choice as the dependent variable to test for order effects in the memory-based task condition. No significant differences were found, therefore we collapsed the presentation order factor for all subsequent analyses.

In order to test the effect of task type in the experiment with an added element of cognitive load, two 2 (frame: gain, loss) x 2 (task type: online, memory-based) between-subjects ANOVAs were performed with choice and signed confidence as the dependent variables (see Table 8). There was an overall significant effect of frame (M_{Gain} = 0.31, SD = .46 M_{Loss} = 0.56, SD = .5) and a marginally significant effect of task type, in which participants were more risk averse when the task is memory-based (M_{online} = 0.50 SD = .5, $M_{memory\text{-}based}$ = 0.39, SD = .49). However, task type did not significantly interact with frame, suggesting that the cognitive load manipulation erased any processing advantages provided by the online task type over the memory-based type. As in the previous experiment, a memory score was computed by adding together the number of correct recalled numbers (from 0 – nothing recalled correctly to 6 – everything recalled correctly). Participants' memory score did not differ between frames $t(305) = .068$, *n.s.*, nor did it differ between the online and memory-based task types $t(305) = .169$, *n.s.* To ensure the cognitive load manipulation was effective a t-test was performed between experiments with memory score as the dependent variable. The test confirmed that participants in experiment 1 had significantly better memory performance ($M_{Experiment\ 1}$ = 5.52, SD = 1.02) compared to participants in experiment 2 ($M_{Experiment2}$ = 4.99, SD = .1.67), $t(305) = 4.49$, $p < .0001$, $d = .39$.

Framing and memory for zero-complement. Given that fuzzy-trace theory (FTT) predicts that focusing on the zero-complement in the framing problem (e.g., 2/3 chance 0 people saved/1/3 chance 0 people die) should increase framing effects (Reyna, 2012), analyses were conducted with choice and signed confidence to determine whether framing effects are affected by participants' memory for the zero complement. Correct memory for the zero complement was coded as a 1, and incorrect memory was coded as a 0, and entered as factor with frame (gain, loss) in factorial ANOVAs with choice and signed confidence as dependent variables. Results for choice show a main effect of memory indicating that those who recalled the zero complement were more risk averse overall $F(1, 302) = 4.61$, $p = .033$, $\eta_p^2 = .015$ ($M_{Recall} = .41$, $M_{No\ Recall} = .58$). Signed confidence analysis also reveal a main effect of memory which was moderated by a significant interaction between memory and frame $F(1, 302) = 5.28$, $p = .022$, $\eta_p^2 = .017$. This interaction demonstrates that participants who remember the zero complement only show significantly more risk aversion in the gain frame whereas there is no difference for memory for the zero complement in the loss frame. Overall this result indicates larger framing effects (driven by more risk-aversion in the gain frame) for those who recalled the zero complement (see Figure 2).

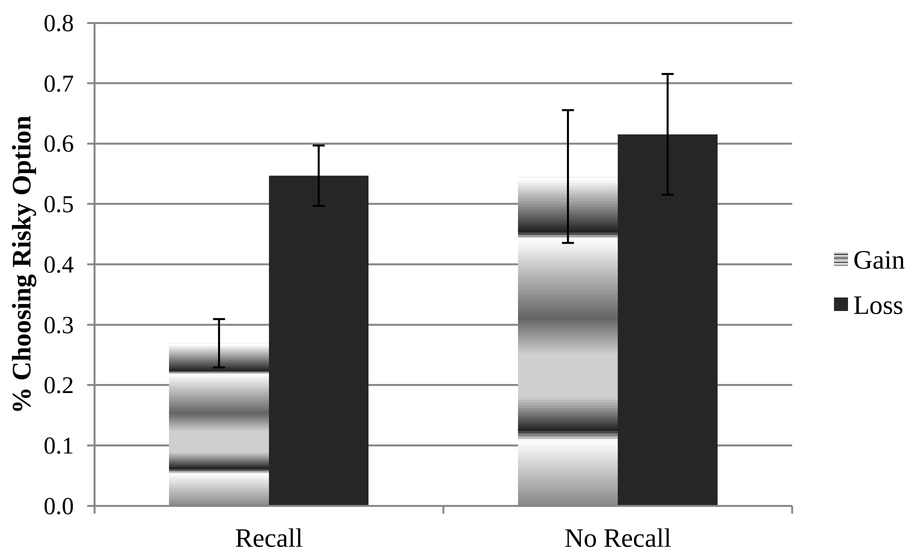

Figure 2. Experiment 2 results for the affect of recalling the zero-complement on framing. *Note:* $N_{Recall} = 258$, $N_{No\ Recall} = 47$. Error bars are Standard Errors based on 1,000 bootstrap samples.

To further explore why this effect was restricted to those in the gain frame, the incorrect responses for those who incorrectly recalled the zero complement were examined for each frame. Overall, we found that the most often misremembered number for participants in the gain frame was six-hundred (36.4% of incorrectly recalled numbers) whereas the most often misremembered number for participants in the loss frame was 200 (24%) and with 16% misremembering 600 people at risk of dying. In the gain frame, incorrectly recalling 600 in place of 0 should lead participants to prefer the risky option, given that in this case there would be a larger chance of saving more people (e.g, now there is a 2/3 chance of saving 600 rather than 0, making the expected value greater in the risky option (2/3 * 600 = 400) as compared to the sure option of saving 200). On the other hand, in the loss frame, misremembering 200 or 600 in place of 0 still leaves fewer people potentially dying in the risky option (e.g., 1/3 * 600 = 200) as compared to the sure option (400 people dying), and should still lead to a preference towards the risky option.

Framing and Memory for the Endowment. Although fuzzy-trace theory predicts that framing effects should be stronger for those that correctly remember the zero complement, the opposite prediction holds for memory for the endowment (e.g., 600 lives total at risk). Without the endowment, the gains and losses versions of the problem would no longer be equivalent. Saving 200 and losing 600 out of a total of 600 are both equivalent, but if there is no denominator (e.g., 600 total), then saving 200 and losing 400 cannot be considered equal outcomes. Therefore, better recall for the endowment allows for the possibility of realizing the equivalency between gains and losses (i.e., subtracting 600 from 200 saved to get 400 lost), which would diminish the effectiveness of the frame.

To test the hypothesis that worse memory for the endowment should result in larger framing, we conducted ANOVAs comparing frame (gain, loss) and memory for the endowment (recall, no recall) with choice and signed confidence as the dependent variables. The results yielded a significant interaction between frame and memory for the endowment for choice $F(1, 302) = 5.98$, $p = .015$, $\eta_p^2 = .019$ and a marginal effect for signed confidence $F(1, 302) = 3.54$, $p = .061$, $\eta_p^2 = .012$ (see Figure 3). Pairwise comparisons showed significant framing for both memory conditions (*p's* < .05), but significantly more risk-averse choices in the gain frame for those who did not correctly recall the endowment compared to those that correctly recalled the endowment ($p = .033$). Therefore the hypothesis is partially supported, with more frame-consistent choices in the gain frame for those who did not recall the endowment.

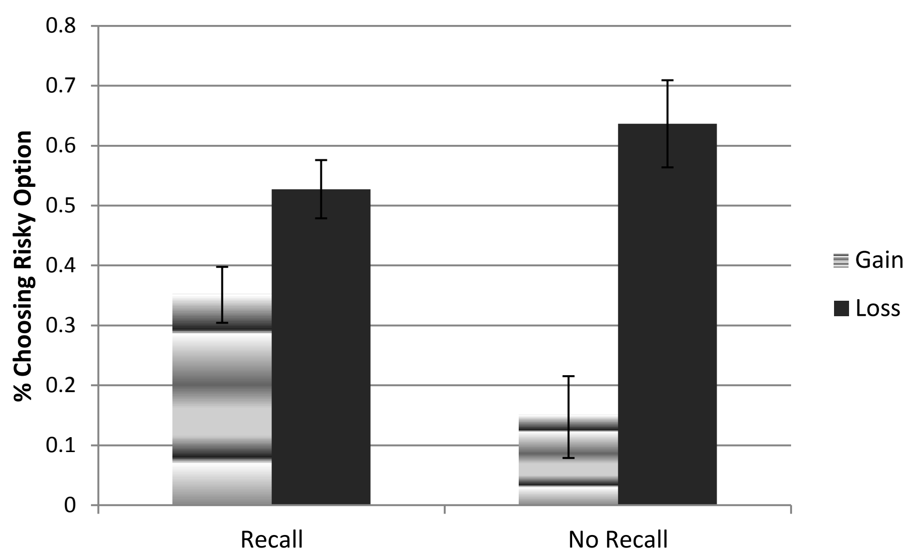

Figure 3. Experiment 2 results for the affect of recalling the endowment on framing. *Note:* $N_{Recall} = 229$, $N_{No\ Recall} = 77$. Error bars are Standard Errors based on 1,000 bootstrap samples.

Working Memory and Numeracy. For the individual differences analyses, a reduced sample of 213 participants was relied on due to software errors that prevented some participants from completing the working memory span task. Descriptive statistics for individual difference measures can be found in Table 6 and correlations in Table 7.

In order to examine the relationships among working memory capacity (WMC), numeracy, and framing on participant's decisions, a factorial logistic regression was performed with framing choice as the dependent measure (see Table 4 for choice analysis and Table 5 for signed confidence analyses). Results show a marginally significant Frame X WMC interaction for choice and a significant interaction for signed confidence in the direction of higher working memory capacity participants showing smaller framing effects – the opposite direction of the previous study. In order to break the relationship between WMC and framing down further, partial correlations were conducted between signed confidence and WMC score controlling for numeracy for each frame (gain or loss) separately. Partial correlations were based on 1,000 bootstrapped samples. For the gain frame, WMC and choice were not significantly correlated $r_{wmc,\text{choice.numeracy}} = -.12$, $df = 103$, p = n.s., 95% CI [-.32, .08]; however, there is a significant negative correlation between WMC and choice in the loss frame such that higher WMC is related to more risk-averse decisions in the loss frame $r_{wmc,\text{ choice.numeracy}} = -.21$, $df = 104$, $p = .033$, 95% CI [-.39, -.04].

In order to determine the relationship between working memory capacity and memory for problem information, point-biserial correlations were ran between working memory scores, and measures of memory for the zero-complement and endowment (1,000 bootstrapped samples). Given that only a relationship between WMC and framing was found for the loss frame, analyses were conducted separately for each frame. For the gain frame, those with higher WMC were more likely to recall the zero-complement $r_{pb}(106) = .21$, $p = .03$, 95% CI [-.08, .46], but there was no significant relation between WMC and memory for the endowment $r_{pb}(106) = -.03$, p = n.s., 95% CI [-.21, .18].

However, in the loss frame, there was both a significant positive relationship between WMC and memory for the zero complement $r_{pb}(107) = .43$, $p < .0001$, 95% CI [.16, .66] as well as between WMC and memory for the endowment $r_{pb}(107) = .37$, $p < .0001$, 95% CI [.16, .55].

Discussion

The increased demand on memory in Experiment 2 allowed for an examination of the relationships between memory for theoretically important aspects of the problem and decision making. Results supported the hypothesis that memory for the zero-complement should be related to framing whereas memory for the endowment should show the opposite relation. Furthermore, we saw working memory scores show a similar pattern as memory for the endowment with respect to framing decisions. Those with higher WMC were better able to recall the endowment, which leaves open the possibility for spontaneously converting between frames (e.g., mentally subtracting 200 saved from the 600 at risk to get 400 dying). Although higher WMC was also related to memory for the zero-complement as well (and overall memory; see Table 7), the endowment was more difficult to recall (77 participants failed to recall the endowment compared to 47 participants for the zero-complement). so In this case, an emphasis on recalling problem information for memory tests as opposed to understanding the problem as a whole for a decision was associated with less biased decisions in those with higher WMC.

General Discussion

Many theories of decision-making assume that biased decision-making is largely due to the reliance on a fast, intuitive processing of information, which is independent of working memory resources (Evans, 2008; Kahneman & Frederick, 2002). One specific decision bias, the framing effect, occurs when individual's treat quantitatively equivalent information differently when described in qualitatively different terms. Traditionally, this bias has been explained by positing that individuals transform quantitative outcomes into subjective amounts which differ when framed in terms of gains as opposed to losses (Kahneman & Tversky, 1979). More recently, research based on fuzzy-trace theory has demonstrated that framing effects are a result of relying on the overall gist of the problem. Specifically, in the gain frame, the gist of the choice is between saving some and saving none or in the loss frame, losing some or losing none (Kuhberger & Tanner, 2010; Reyna & Brainerd, 1995; Reyna, 2012).

The current research concerns whether processing limitations underlie the inability to inhibit the biased intuitions that result in framing effects. Whereas traditional theories assume this to be the case, the results of these studies provide evidence to the contrary. When the difficulty of the framing task was increased by forcing participants to rely on their memory for the problem, framing effects either decreased as compared to when participants had complete information at the time of decision, or were no different (when memory demands were increased). These results provide more support for the hypothesis that framing effects are not a result of simple heuristics, but are due to meaningfully representing the problem. Interestingly, demonstrating that recollection of the zero-complement in the gain frame led to decisions that were more consistent with traditional framing (i.e., risk-aversion) and that recalling the endowment led to less framing-consistent choices also lends support to FTT's conception of framing effects.

A second goal of this paper was to determine the relationship between working memory capacity (WMC) and numeracy as they relate to framing effects given the differences in how each individual-difference measure has been related to framing in the past literature. In Experiment 1, the positive relationship between framing and WMC found in Corbin, McElroy, and Black (2010) was replicated, but taken further when combined with numeracy to show that this effect is only present when combined with low numeracy.

Furthermore, when demands on memory were increased, the relationship between framing and WMC echoed the relationship between actual memory for the problem and framing. These results reflect the nature of working memory as a processing capacity. Working memory can be flexibly used to achieve many goals. In this case when there are no other demands on WMC, low numerate individuals may use this resource to meaningfully interpret the framing problem, whereas high numerate individuals may use this resource to rely on rote calculation. Finally, when WMC is being tapped for a separate task (e.g., a concurrent memory task), high WMC individuals will better recall the memory items, and results between framing bias and WMC should reflect those between memory for the problem and framing. In the context of fuzzy-trace theory, WMC supports both verbatim or gist processing, which is relied on to different degrees depending on an individual's propensity as well as task demands. Most adults, however, rely primarily on gist processing, but this propensity decreases when people are able to quickly and automatically calculate proportions (what numeracy tests measure; Reyna, Nelson, Han, & Dieckmann, 2009), such as those involved in tradeoffs in probability and outcome.

Conclusion

In sum, this paper supports the hypothesis that framing effects are not a result of processing limitations, but rather arise due to individual differences in thinking styles. Furthermore, framing effects appear to be less robust when restrictions are put on one's ability to meaningfully process the problem information, thus supporting fuzzy-trace theory's conception of framing effects (Reyna, 2012). Further support is gained when looking at how numeracy interacts with WMC demonstrating a positive relationship with framing with those who are less facile at rote calculation (and therefore may prefer to rely on gist), but a negative relationship with framing for those who calculation comes more easily (and therefore may prefer to rely on verbatim processing).

Whereas previous research supports the view that current measures of numeracy tend to reflect verbatim processing (Liberali, et al., 2012), recently work in FTT has begun to test measures of gist numeracy, which capture ones understanding of what numbers mean rather than just calculation ability (Reyna, Brust-Renk, & Portenoy, 2012, October). Given that FTT predicts that framing effects are due to representing the problem as a some/none categorical gist, the further prediction follows that individuals' higher in gist numeracy should show larger framing effects as compared to individuals' low in gist numeracy.

Finally, a limitation of this research is the failure to distinguish the contribution of gist versus verbatim memory processes as they related to participants' ability to recall the information from the framing problem. Research in the memory literature has demonstrated that both gist and verbatim memory contribute to participants' recall on memory tests, and furthermore that each memory process is dissociated from the other (Brainerd, Reyna, & Mojardin, 1999; Brainerd, Wright, Reyna, & Mojardin, 2001;

Brainerd, Wright, Reyna, & Payne, 2002). Given that gist memory remains accessible for much longer than verbatim memory, FTT would predict that framing effects should remain robust long after verbatim information is forgotten, provided participants encode the gist when initially given the problem. Furthermore, the analyses relating recall to choice were quasi-experimental, and therefore a number of other factors could be at play with respect to these results. It is important for future studies relating memory to decision making to take timing of memory tests into account when considering the design of memory studies and interpretation of their results.

Overall, these studies have demonstrated that bias in framing problems is not a result of memory capacity limitations. Rather, differences in decision bias arise through different ways of processing the information. Framing effects are reduced when one does not process the problem meaningfully, and prefers to use verbatim calculation as opposed to gist processing. Results from these studies as well as others (see Igou & Bless, 2007), suggest that it is possible to cue preference for one or the other types of processing (e.g., Mills, Reyna, & Estrada, 2008). That it is possible to cue one or the other types of processing, cuing rote, verbatim calculation when a meaningful interpretation is not warranted, or cuing gist processing when one desires understanding over precision. Future studies should examine the conditions under which each type of processing is beneficial.

APPENDICES

Appendix A: Tables

Table 1

Frame X Task Type X Presentation Order ANOVAs for Choice and Signed Confidence in Experiment 1

	Decision			Signed Confidence	
Factor	Df	F	η_p^2	F	η_p^2
Frame	1	38.25^{***}	.13	37.33^{***}	.16
Task Type	1	.06	.00	.59	.00
Presentation Order	1	.00	.00	.17	.00
Frame X Task Type	1	3.91^{*}	.02	1.79	.01
Frame X Presentation Order	1	.13	.00	.06	.00
Task Type X Presentation Order	1	3.06	.01	2.36	.01
Frame X Task Type X Presentation Order	1	5.78^{*}	.02	3.96^{*}	.02
Error	248				
Total	256				

$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 2

Descriptive Statistics for Individual Differences in Experiment 1

	N	Min	Max	Mean	Std. Deviation
WMC	163	37.00	60.00	56.1840	3.33933
Numeracy	244	4.00	11.00	9.3893	1.61782
Memory Score	257	.00	6.00	5.5019	1.07937
Raven's Adv. Matrices	237	.00	11.00	6.7468	2.75774

Note: WMC = Working Memory Capacity, Memory Score = Framing Memory Score

Table 3

Pearson Correlations Between Individual Difference Scales and Framing Memory Score for Experiment 1

	WMC (*95% CI*)	Numeracy (*95% CI*)	Memory Score (*95% CI*)	Raven's Adv. Matrices (*95% CI*)
WMC	-	.1 (-.03, .25)	.16* (-.1, .44)	.21** (.06, .36)
Numeracy	-	-	.15† (-.02, .38)	.39*** (.26, .51)
Memory Score	-	-	-	.35*** (.21, .45)

Note: 95% CI's based on 1,000 bootstrapped samples.
WMC = Working Memory Capacity, Memory Score = Framing Memory Test, Raven's Adv. Matrices = Raven's Advanced Progressive Matrices Score.
N=161.
$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 4

Summary of Logistic Regression Analyses for Variables Predicting Framing Choice for Experiments 1 and 2

	Experiment 1			Experiment 2		
Predictor	*B* *(95% CI)*	*SE B*	e^B	*B* *(95% CI)*	*SE B*	e^B
Frame	-1.6^{**} (-2.6, -0.91)	.43	0.2	-1.2^{**} (-2.2, -0.55)	.42	0.3
WMC	-.08 (-0.18, 0.39)	.14	1.08	-0.27^{*} (-0.62, -0.12)	.13	0.77
Numeracy	.01 (-0.4, 0.37)	.19	1.01	0.5^{**} (0.18, 1.05)	.23	1.64
Frame X WMC	$-.32^{*}$ (-0.77, -0.01)	.19	0.728	$0.23^{\dagger}$ (0.03, 0.68)	.17	1.26
Frame X Numeracy	$.48^{\dagger}$ (-0.01, 1.27)	.33	1.61	-0.45 (-1.1, 0.2)	.33	0.64
WMC X Numeracy	-.11 (-0.29, 0.09)	.05	0.9	$-0.1^{\dagger}$ (-0.33, -0.02)	.08	0.9
Frame X WMC X Numeracy	$.20^{*}$ (-0.01, 0.52)	.13	1.22	0.05 (0.27, 0.28)	.13	1.05
Constant	.48	.27	1.62	0.42 (-0.05, 1.21)	.32	1.5
χ^2	32.09^{***}			28.33^{***}		
Df	7			7		

Note: e^B = exponentiated *B*. WMC = Working Memory Capacity score. For the Frame parameter, the gain frame is set as the reference category. Standard errors, 95% Confidence intervals and p-values based on 1,000 bootstrap samples. All continuous variables are mean-centered. Experiment 1 N = 161; Experiment 2 N = 213.

$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 5

Summary of Linear Regression Analyses for Variables Predicting Signed Confidence for Experiments 1 and 2.

	Experiment 1			Experiment 2		
Predictor	B *(95% CI)*	*SE B*	*Β*	B *(95% CI)*	*SE B*	*Β*
Frame	-3.3** (-4.67, -1.84)	.7	-.36	-2.62** (-3.8, -1.46)	.64	-.3
WMC	.03 (-0.49, 0.59)	.27	.02	-0.04 (-0.23, 0.16)	.1	-.05
Numeracy	.09 (-0.61, 0.69)	.33	.03	-0.02 (0.18, 1.05)	.35	-.01
Frame X WMC	-.43 (-1.05, 0.12)	.3	-.28	0.32* (0.05, 0.69)	.16	.26
Frame X Numeracy	.23 (-0.62, 1.15)	.57	.05	-0.66 (-1.51, 0.24)	.46	-.14
WMC X Numeracy	-.22 (-0.45, 0.17)	.15	-.21	-0.15* (-0.34, -0.03)	.08	-.28
Frame X WMC X Numeracy	.27† (-0.13, 0.59)	.18	.22	-0.01 (-0.22, 0.22)	.11	-.02
Constant	1.25** (.184, 2.3)	.51		-1.82** (-2.7, -0.91)	.45	
F	4.65***			4.54***		
Df	7			7		
Adj. R^2	.14			.11		

Note: WMC = Working Memory Capacity score. For the Frame parameter, the gain frame is set as the reference category. Standard errors, 95% Confidence intervals and p-values based on 1,000 bootstrap samples. All continuous variables are mean-centered. Experiment 1 N = 161; Experiment 2 N = 213.

†p < .1, *$p < .05$, **$p < .01$, ***$p < .001$.

Table 6

Descriptive Statistics for Individual Differences in Experiment 2

	N	Min	Max	Mean	Std. Deviation
WMC	214	31.00	60.00	55.4252	4.88281
Numeracy	289	3.00	11.00	8.9827	1.34747
Memory Score	307	.00	6.00	4.9870	1.66465
Raven's Adv. Matrices	276	.00	11.00	6.5507	2.58548

Note: WMC = Working Memory Capacity, Memory Score = Framing Memory Score

Table 7

Pearson Correlations Between Individual Difference Scales and Framing Memory Score for Experiment 2

	WMC (*95% CI*)	Numeracy (*95% CI*)	Memory Score (*95% CI*)	Raven's Adv. Matrices (*95% CI*)
WMC	-	$.21^{**}$ (.04, .38)	$.33^{***}$ (.12, .53)	$.3^{**}$ (.17, .42)
Numeracy	-	-	$.24^{**}$ (.09, .39)	$.42^{***}$ (.29, .54)
Memory Score	-	-	-	$.27^{***}$ (.13, .41)

Note: 95% CI's based on 1,000 bootstrapped samples.
WMC = Working Memory Capacity, Memory Score = Framing Memory Test, Raven's Adv. Matrices = Raven's Advanced Progressive Matrices Score.
N=213.
$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 8

Frame X Task Type X Presentation Order ANOVAs for Choice and Signed Confidence in Experiment 2

	Decision			Signed Confidence	
Factor	df	F	η_p^2	F	η_p^2
Frame	1	21.12^{***}	.07	28.78^{***}	.09
Task Type	1	$3.84^{\dagger}$	.01	$3.13^{\dagger}$	.01
Frame X Task Type	1	.61	.00	.748	.00
Error	302				
Total	306				

$^{\dagger}p < .1$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Appendix B: Means and Standard Errors for Figures

Table 9
Means and Standard Errors for Figure 1.

		Gain Frame	Loss Frame
Task Type	Presentation Order	Mean (SE)	Mean (SE)
Memory-Based	Decision First	.44 (.09)	.56 (.09)
Memory-Based	Decision Second	.22 (.07)	.58 (.08)
Online	Decision First	.07 (.05)	.70 (.09)
Online	Decision Second	.33 (.08)	.65 (.09)

Note: Standard Errors based on 1,000 bootstrapped samples.

Table 10
Means and Standard Errors for Figure 2.

Memory for Zero-	Gain Frame	Loss Frame
Complement	Mean (SE)	Mean (SE)
Recall	.27 (.04)	.55 (.05)
No Recall	.55 (.11)	.62 (.10)

Note: Standard Errors based on 1,000 bootstrapped samples.

Appendix C: Framing Materials

Framing problem:

Please read the scenario below carefully. Treat all numerical values in the problem below as exact values.

Imagine that the US is preparing for the outbreak of an unusual disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimates of the consequences of the programs are as follows:

If Program A is adopted, 200 people will be saved.

If Program B is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that 0 people will be saved.

Decision Prompt

Which program would you choose? If you are unsure of what the correct answer is, please enter a response that seems right to you. Any answer is better than no answer.

Program A

Program B

Confidence Measure:

Please rate how confident you are in your decision on the following scale:

1: Not at all Confident

2

3

4: Medium Confidence

5

6

7: Completely Confident

Memory Test

Fill in each blank with the information that you remember from the scenario that you just read. If you are unsure of what the correct answer is, please enter a response that seems right to you. Any answer is better than no answer. Each of these responses requires that a number be entered. If you do not remember the exact number, enter what you think may be the correct number.

The US is preparing for the outbreak of an unusual disease, which is expected to kill ___A__ people.

If Program A is adopted, __B__ people will be saved.

If Program B is adopted, there is __C__ probability that __D__ people will be saved, and a __E__ probability that __F__ people will be saved.

A:

B:

C:

D:

E:

F:

Appendix D: Experiment 2 Cognitive Load Tasks

Conjunction Task

Please read the scenario below carefully.

Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.

Indicate the relative probability of three statements that describe Linda:

It is __ that Linda is a teacher in an elementary school.

It is __ that Linda works in a bookstore and takes yoga classes

It is __ that Linda is a bank teller.

It is __ that Linda is a bank teller and active in the feminist movement.

1. Extremely Improbable
2. Very Improbable
3. Somewhat Probable
4. Moderately Probable
5. Very Probable
6. Extremely Probable

In each space below, please list an item that was used to describe Linda in the above problem. List as many items as you can remember from the scenario above.

Outcome Bias Task

Please read the following problem carefully. Treat all numerical values in the problem below as exact values.

A 55 year old man had a heart condition. He had to stop working because of chest pain. He enjoyed his work and did not want to stop. His pain also interfered with other things, such as travel and recreation. A type of bypass operation would relieve his pain and increase his life expectancy from age 65 to age 70 (75). However, 8% (3%) of the people who have this operation die from the operation itself. His physician decided to go ahead with the operation. The operation succeeded (failed).

Evaluate the physician's decision to go ahead with the operation.

1. Incorrect, a very bad decision.
2. Incorrect, all things considered.
3. Incorrect, but not unreasonable.
4. The decision and its opposite are equally good.
5. Correct, but the opposite would be reasonable too.
6. Correct, all things considered.
7. Clearly correct, an excellent decision.

Fill in each blank with the information that you remember from the scenario that applies. If you are unsure of what the correct answer is, please enter a response that seems right to you. Each of these responses requires that a number be entered. If you do not remember the exact number, enter what you think may be the correct number.

A _A_ year old man had a heart condition. He had to stop working because of chest pain. He enjoyed his work and did not want to stop. His pain also interfered with other things, such as travel and recreation. A type of bypass operation would relieve his pain and increase his life expectancy from age _B_ to age _C_. However, _D_% of the people who have this operation die from the operation itself. His physician decided to go ahead with the operation. The operation succeeded.

A:

B:

C:

D:

Anchoring Tasks

Please read the sentence below carefully.

Do you think there are more or less than 65 (12) African countries in the United Nations?

Do you think there are less or more African Countries?

A. More

B. Less

How many African countries do you think are in the United Nations (Only enter a number in the space provided)?

Fill in each blank with the information that you remember from the scenario that applies. If you are unsure of what the correct answer is, please enter a response that seems right to you. Each of these responses requires that a number be entered. If you do not remember the exact number, enter what you think may be the correct number.

Do you think there are more or less than _____ African countries in the United Nations?

Please read the sentence below carefully.

Is the tallest redwood tree in the world more than 85 (1,000) feet tall?

Do you think the tallest redwood tree is more or less tall?

A. More

B. Less

How tall is the tallest redwood tree in the world (only enter a number in the space provided)?

Fill in each blank with the information that you remember from the scenario that applies. If you are unsure of what the correct answer is, please enter a response that seems right to you. Each of these responses requires that a number be entered. If you do not remember the exact number, enter what you think may be the correct number.

Is the tallest redwood tree in the world more than ___ feet tall?

Base Rate Task

Please read the following problem carefully. Treat all numerical values in the problem below as exact values.

A panel of psychologists have interviewed and administered personality tests to 70 (30) engineers and 30 (70) lawyers, all successful in their respective fields. On the basis of this information, a thumbnail description of the 70 (30) engineers and 30 (70) lawyers has been written. For the description, please indicate your probability that the person described is an engineer, on a scale from 0 to 100. The same task has been performed by a panel of experts, who were highly accurate in assigning probabilities to the various descriptions.

Jack is a 45-year-old man. He is married and has four children. He is generally conservative, careful, and ambitious. He shows no interest in political and social issues and spends most of his free time on his many hobbies which include home carpentry, sailing, and mathematical puzzles.

The probability that Jack is one of the engineers in the sample is ____%

Fill in each blank with the information that you remember from the scenario that applies. If you are unsure of what the correct answer is, please enter a response that seems right to you. Each of these responses requires that a number be entered. If you do not remember the exact number, enter what you think may be the correct number.

A panel of psychologists have interviewed and administered personality tests to _A_ engineers and _B_ lawyers.

A:

B:

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